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United States
Department of
Agriculture

Forest Service

Forest Pest
Management

Davis, CA

A Working Paper on Net Radiation Index

FPM 92-13
April 1992

FPM 92-13
C.D.I. Technical Note. 92-10
April 1992

A Working Paper on Net Radiation Index

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Summary

An important meteorological input into FSCBG (Teske et al., 1992) is net radiation index N, a measure of the influence of solar radiation on atmospheric motion. This parameter sets several atmospheric stability variables for the subsequent FSCBG calculation (including wind speed power law exponent, azimuthal and elevation standard deviations, and mixing layer height); its value impacts the prediction of spray cloud growth and expansion. Over the years FSCBG documentation and training session materials have focused on several field-observation approaches to establishing the value of N. Some rules-of-thumb have been suggested that basically end with setting N = 1 since the USDA Forest Service recommends spraying in the early morning hours.

Recently, several members of the FSCBG community have questioned whether N could be better quantified, based either on a more analytical approach or by incorporating an on-site field measurement of incoming solar radiation. This paper summarizes an effort at examining the prediction of N by these approaches.

Net Radiation Index

The stability character of the atmosphere affects any material released into it. Pasquill (1961) first proposed a simple technique whereby dispersion estimates could be generated in terms of routine meteorological data. This system was subsequently modified by Gifford (1961) into a format widely known today as the Pasquill-Gifford curves. These curves enable a researcher to estimate the horizontal and vertical dispersion characteristics of a plume release, using readily available meteorological information. Cramer (1957) made significant contributions to this technique, while Turner (1970) assembled sources of information into a substantial resource workbook for estimating atmospheric dispersion.

Traditionally, atmospheric stability is divided into seven stability classes:

Stability Category	Stability Effect	Stability Parameter
A	very unstable	1
B	unstable	2
C	slightly unstable	3
D	neutral	4
E	slightly stable	5
F	stable	6
G	very stable	7

Atmospheric stability is dependent primarily upon net radiation and wind speed. In the absence of cloud cover, incoming solar radiation (or insolation) during the day is dependent only upon solar altitude (the position of the sun above the horizon), which is a function of time of day, time of year and location. Turner (1964) developed a technique whereby the solar altitude and actual cloud cover could be used to infer what he called the net radiation index. This index could then be correlated with wind speed to determine the stability parameter and quantify the stability effect.

The cookbook procedure works like this (following Turner, 1964, and Fulle, 1976):

1) Determine the Insolation Class. From field observations at the time of the spray mission, the insolation class number I is determined by knowing the solar altitude (where 90 deg is overhead in the sky) using the table:

Solar Altitude Angle A (deg)	Insolation	Insolation Class Number I
$60 < A < 90$	strong	4
$35 < A < 60$	moderate	3
$15 < A < 35$	slight	2
$0 < A < 15$	weak	1

2) <u>Correct for Cloud Cover</u>. The following steps are then taken:

1. If the total cloud cover is 10/10 (overcast) and the cloud ceiling is less than 7,000 feet, net radiation index N = 0 (daytime or nighttime).

2. For nighttime (between sunset and sunrise) when the total cloud cover is greater than 4/10 and less than 10/10, N = -1; when the total cloud cover is less than 4/10, N = -2.

3. For daytime when the total cloud cover is less than 5/10, net radiation index equals the insolation class number, N = I.

4. For daytime when the total cloud cover is greater than 5/10, net radiation index is obtained by modifying the insolation class number by:

    a. When the cloud ceiling is less than 7,000 feet, N = I - 2.

    b. When the cloud ceiling is greater than 7,000 feet and less than 16,000 feet, N = I - 1.

    c. When the total cloud cover is 10/10 and the cloud ceiling is greater than 7,000 feet, N = I - 1.

    d. Otherwise, N = I.

    e. Plus, N must not be less than 1.

The resulting value of N is entered at the appropriate place in the FSCBG data input. Table entries are then manipulated by FSCBG to determine the necessary meteorological parameters (Dumbauld and Bowers, 1983). The tabular relationship determining the stability class, for example, is found from the table (Turner, 1964, and Fulle, 1976):

Wind Speed	Net Radiation Index N						
(knots)	4	3	2	1	0	-1	-2
0,1	1	1	2	3	4	6	7
2,3	1	2	2	3	4	6	7
4,5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8,9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
12	3	4	4	4	4	4	4

The curve fits used in FSCBG to extract the necessary atmospheric parameters compress the N = -2 value into N = -1 (Bjorklund et al., 1984). This procedure appears the most workable, and is strongly recommended.

[illegible] Cloud gamma. The following steps are then taken:

If the total cloud cover is 10/10 (overcast) and the cloud ceiling is [illegible] [illegible] radiation index N = 0 (daytime or nighttime).

[illegible] nighttime (between sunset and sunrise) [illegible] and less than [illegible] N = [illegible] then [illegible] N = -2.

For daytime when the total cloud cover is less than 10/10, [illegible] equals the insolation class number, N = I.

For daytime when the total cloud cover [illegible] [illegible] the insolation class number [illegible]

[illegible] the cloud ceiling is less than 7,000 feet, N = I - 2.

b. When the cloud ceiling is greater than [illegible] N = I - 1.

When the total cloud cover is 10/10 and the cloud ceiling is greater [illegible] feet, N = I - 1.

Otherwise, N = I

Plus, N must not be less than 1.

The resulting value of N is entered in the appropriate [illegible] of the [illegible] Table entries are then manipulated by ESCPG to determine the necessary [illegible] parameters (Donald and Bowers, 1985). The tabular relationship [illegible] stability class, for example, is found from the table (Turner, 1964, and [illegible]

Net Radiation Index N

4 3 2 1 0 -1 -2

[illegible]

Jim Rafferty (private communication) has provided an equation set to recover the solar altitude at any location and time on the earth. A simplification of these equations defines the following computational procedure:

ϕ = latitude (positive north)

T = local time in hours

$$d = 0.985648\,(\text{Julian Day} - 1)$$

$$M = 12.0 + 0.12357 \sin d - 0.004289 \cos d + 0.153809 \sin 2d + 0.060783 \cos 2d$$

$$\sigma = 279.9348 + d + 1.914827 \sin d - 0.079525 \cos d + 0.019938 \sin 2d - 0.00162 \cos 2d$$

$$D = \arcsin(0.39785 \sin \sigma)$$

$$h = 15\,(T - M)$$

A = solar altitude angle

$$= \arcsin(\sin \phi \sin D + \cos \phi \cos D \cos h)$$

This information has been collected into a QuickBasic computer program for recovering an approximate value for net radiation index. A listing of this program is provided in the Appendix of this report. This program assumes that each time zone covers 15 degrees of longitude, and that daylight occurs between 6 AM and 6 PM.

It is anticipated that a more complete equation formulation (developed from the Real Time Volume Source Model at U. S. Army Dugway Proving Ground) will be included in a later version of FSCBG.

Solar Radiation

A suggested alternate approach for recovering net radiation index is to make use of a direct measurement of incoming solar radiation. The applicability of this approach will now be discussed (following Geiger, 1965).

Radiation arrives at the earth's surface from the sun, and reflects by several physical processes through the atmosphere. A positive net radiation adds heat to the surface of the earth. Radiation is usually measured in calories per square centimeter per minute (cal/sq cm min), also called langley per minute (ly/min). Units conversion is:

$$1 \frac{\text{ly}}{\text{min}} = 1 \frac{\text{cal}}{\text{cm}^2\,\text{min}} = 697.4 \frac{\text{W}}{\text{m}^2} = 221.2 \frac{\text{Btu}}{\text{hr ft}^2}$$

Net radiation may be denoted by the symbol S. If insolation (incoming solar radiation) is greater than outgoing (or terrestrial) radiation, the radiation balance is positive; if it is less, the radiation balance is negative. The radiation balance consists of two radiation streams of different spectral ranges. The first radiation stream is a short-wavelength part available only when the sun shines. Radiation reaching the surface of the earth consists of that part of direct incoming solar radiation I not reflected by clouds, absorbed by the atmosphere, or scattered diffusely, and that part of the nondirectional sky radiation H that represents diffusely scattered radiation that has reached the ground and provides "daylight" within the visible spectrum. The value of $I + H$ reaching a horizontal surface is called global radiation. Part of this radiation is in turn reflected by the earth's surface. This short-wavelength reflected radiation R depends on the nature of the ground. Dave Miller (private communication) has provided some insight into the measurement of the reflection factor within a canopy, referencing work by Monteith (1976).

The second radiation stream is due to incoming long-wavelength radiation. The earth's atmosphere contains water vapor, carbon dioxide, and ozone, all of which absorb radiation and re-emit it. The long-wavelength atmospheric radiation G is termed counter-radiation since it counteracts the terrestrial radiation loss. It occurs both day and night, and in fact is somewhat greater during the day since it depends on temperature.

In addition, the earth's natural surface cover acts as a black body to emit radiation through the soil surface by day and night according to the Stefan-Boltzmann fourth-power temperature law σT^4. The radiation balance S is therefore given by the equation:

$$S \quad = \quad I + H + G - \sigma T^4 - R$$

The net radiation S is seen to be a balance of several terms, some (such as G and σT^4) potentially an order of magnitude larger than the others. Thus, it seems clear that the best field measurement to make would be for net radiation. Unfortunately, no currently available instrument is likely to possess the skill needed to produce this measurement (by being able to sort out the competing radiation terms). Rather, the direct incoming solar radiation I has been found to be measurable, and has thus been correlated with stability in

Solar Radiation

A summary is also here presented [illegible] radiation [illegible] effect [illegible] of the cooling solar [illegible] "the [illegible]" [illegible] following Geiger, 1965).

Radiation [illegible] earth's surface [illegible] from the sun [illegible] through the atmosphere. A positive [illegible] of the earth. Radiation [illegible] (called [illegible] also called [illegible] per [illegible] (ly/min). [illegible]

$$[illegible]$$

[illegible] radiation [illegible] denoted by the symbol S. If [illegible] [illegible] is greater than outgoing or terrestrial radiation [illegible] [illegible] is less, the radiation balance is negative. [illegible] different spectral ranges. The [illegible] radiation [illegible] available only when the sun shines. Radiation [illegible] surface [illegible] of that part of these incoming solar rays [illegible] reflected by [illegible] atmosphere, [illegible] scattered diffusely, and that part of the nondirectional [illegible] diffusely scattered radiation that has reached the ground [illegible] "daylight" within the visible spectrum. The [illegible] surface is called global radiation. Part of this radiance is in turn reflected [illegible] surface. This short wavelength reflected radiation [illegible] the [illegible] Dave Miller (private communication) has provided some insight into the [illegible] of the reflection factor within a canopy, between the work by [illegible]

[illegible] second radiation stream is due to incoming long wavelength [illegible] atmosphere contains water vapor, carbon dioxide, and ozone, all of which [illegible] [illegible] it. The long-wavelength atmospheric radiation [illegible] is termed [illegible] [illegible] counter [illegible] terrestrial radiation loss. It occurs both day and night, [illegible] greater [illegible] the day since it depends on temperature.

In addition, the earth's ground surface [illegible] a black body [illegible] radiation [illegible] the soil surface by [illegible] according to the Stefan-Boltzmann [illegible] temperature law σT^4 [illegible] balance S is therefore given by the equation:

[illegible]

the literature. The stability tables have been reworked for incoming solar radiation, either in graphical form (Pasquill and Smith, 1983) or tabular form (Williamson and Krenmayer, 1980) as:

Wind Speed	Incoming Solar Radiation (ly/min)							
(knots)	0.0-0.1	0.2-0.3	0.4	0.5	0.6-0.7	0.8-0.9	1.0-1.1	1.2
0-3	4	2	2	2	2	1	1	1
4-5	4	3	3	2	2	2	1	1
6	4	4	3	3	3	2	2	2
7	4	4	3	3	3	3	2	2
8	4	4	4	3	3	3	2	2
9	4	4	4	3	3	3	3	2
10-11	4	4	4	4	3	3	3	3
12	4	4	4	4	4	3	3	3

In this table the incoming solar radiation and wind speed would be used to determine the stability parameter, which would then be backfit in the Net Radiation Index table. The advantage of this approach is that cloud cover, cloud height, location and time of day are not needed; the disadvantage is that the recovery of net radiation index may not produce a unique value for N. For example, for incoming solar radiation of 0.2 ly/min and a wind speed of 6 knots, a stability parameter of 4 is obtained from the Incoming Solar Radiation table (above). A value of 4 in the Net Radiation Index table suggests a value of N of 1 or 0. Since FSCBG will accept and use non-integer values of N, the appropriate data input entry is probably N = 0.5.

If this approach proves worthwhile, it could be quantified and included in a later version of FSCBG as well.

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Appendix
Source Listing of NETRAD.BAS

```
CLS
PRINT "Net Radiation Index Determination"
PRINT "---------------------------------"
PRINT "Enter the following information as decimal values:"
PRINT
INPUT "North Latitude (deg): ", P
PR = 0.0174533*P
INPUT "Local Time (0.0 to 24.0 hours): ", T
DN = 0
IF T > 6.0 AND T < 18.0 THEN DN = 1
INPUT "Julian Day (1 to 366): ", J
D = 0.985648*(J-1)
DR = 0.0174533*D
SD = SIN(DR)
CD = COS(DR)
STD = SIN(2.0*DR)
CTD = COS(2.0*DR)
M = 12.0+0.12357*SD-0.004289*CD+0.153809*STD+0.060783*CTD
H = 15.0*(T-M)
HR = 0.0174533*H
S = 279.9348+D+1.914827*SD-0.079525*CD+0.019938*STD-0.00162*CTD
SR = 0.0174533*S
TEM = 0.39785*SIN(SR)
DD = ATAN(TEM/SQR(1.0-TEM*TEM))
TEM = SIN(PR)*SIN(DD)+COS(PR)*COS(DD)*COS(HR)
A = 57.29578*ATAN(TEM/SQR(1.0-TEM*TEM))
I = 4
IF A < 60.0 THEN I = 3
IF A < 35.0 THEN I = 2
IF A < 15.0 THEN I = 1
INPUT "Cloud Cover Fraction (0.0 to 1.0): ", CC
CH = 0.0
IF CC > 0.5 THEN INPUT "Cloud Ceiling in 1000s of feet (1 to 30): ", CH
IF CC > 0.95 AND CH < 7.0 THEN
  N = 0
ELSE
  IF DN = 0 THEN
    IF CC < 0.4 THEN
      N = -2
    ELSE
      N = -1
    END IF
  ELSE
    N = I
    IF CC > 0.5 THEN
      IF CH < 16.0 THEN N = I-1
      IF CH < 7.0 THEN N = I-2
      IF CC > 0.95 AND CH > 7.0 THEN N = I-1
      IF N < 1 THEN N = 1
    END IF
  END IF
END IF
PRINT
PRINT "Net Radiation Index: "; N
END
```